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Alternative Sewer Systems in the United States

Municipal Environmental Research Lab.
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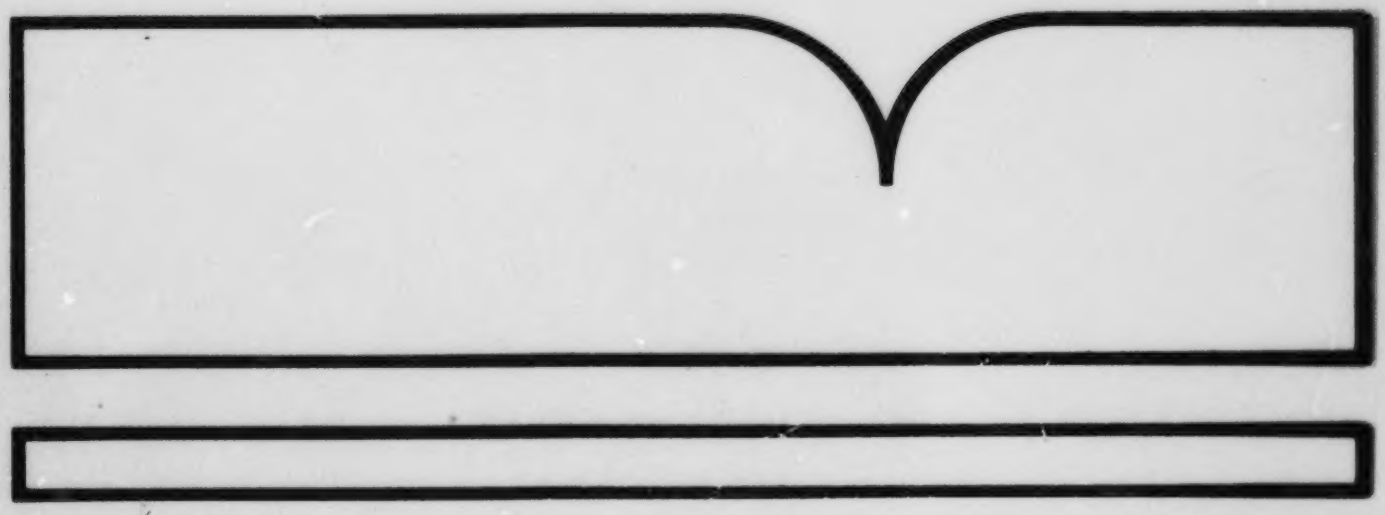

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16. ABSTRACT

The problem of sewering small communities is generally one of prohibitive economics. In response to this problem alternative sewering methods which are lower in cost than conventional gravity sewers have been developed over the past two decades. The major alternative sewering methods are pressure, vacuum and small-diameter gravity systems. Their history costs and performance to date are discussed in a comprehensive manner.

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ALTERNATIVE SEWER SYSTEMS IN THE UNITED STATES

by James F. Kreissl, Environmental Engineer

1 B A C K G R O U N D

1.1 PROBLEM

The disposal of human wastes in an environmentally acceptable manner has been a problem throughout history. Historical evidence of early man's struggle to overcome this problem has been recorded and related elsewhere (Bowles, 1972). Little progress has been recorded between the pre-Christian solutions described in the literature and the mid-19th century rebirth of municipal sewage in Europe and the United States, a development that has continued to the present. Between 1857, when the first large American system was installed in Brooklyn, N.Y. and 1905, about 28 million Americans were "sewered." By 1940 more than half of the total U.S. population was served by sewers, and the figure now stands at about 71 percent.

A review of nearly 300 facility plans for rural communities in the United States in the mid-1970's produced the cost relationship shown in Figure 1 for gravity sewer systems. Monthly charges much above $20 are considered excessive in rural areas where median incomes are generally significantly lower than in urban areas. Because most onsite wastewater disposal systems would cost significantly less than $20 monthly, the onsite approach has been generally used in these areas. Difficulties have arisen in areas where conventional onsite systems have failed because of unfavorable soil conditions. Until recently, the result from this condition was almost invariably a recommendation to install conventional sewers in the community. Implementation of this recommendation depended on the financial status of the community, availability of Federal grants, and public attitude. Without getting into a lengthy discussion on the merits and demerits of the grant program and centralized collection and treatment systems, it suffices to note that the cost of conventional sewers is extremely high for most small communities. In fact, it is not uncommon to see engineering estimates in excess of $10,000 per home. Also, the cost of the conventional collection system generally represents more than 80 percent of the total system capital cost in rural

areas. Figure 1 clearly illustrates the relationship between cost and population density, which is primarily explained by the greater length of sewer per contributor or greater problems with grade resulting in more lift stations or excessively deep sewers.

Essentially because of the foregoing economics, the primary form of wastewater treatment and disposal in rural areas has been the septic tank-soil absorption system (ST-SAS). Before the passage of the Norris-Rayburn Act during the depression of the 1930's, few rural areas had the electricity necessary to provide for water carriage of human wastes. However, as the rural electrification program took effect the following decade, two major events occurred. First, the rural population obtained electricity that upgraded the standard of living, including pressurized water supplies and water carriage of wastes. Second, urban dwellers emigrated to previously rural areas, where they could enjoy the best of both societies. The disposal of wastewater generated in these unsewered areas was best accomplished by ST-SAS's. Developers of these areas also found advantages in these systems because costs were directly related to the dwelling and offered a minimum of postconstruction responsibility. Unfortunately, many of these systems have failed because of faulty design and construction, unsuitable soil conditions, and owner negligence. Present estimates indicate, however, that more than 20 million ST-SAS's still exist in the United States, serving more than one-fourth the population.

Unfortunately, many situations have come about in recent years that cannot be solved by either of the traditional options, and the results of attempting to apply either technology in these situations have been unsatisfactory to all involved. For example, building moratoriums have been imposed that prevent the development of highly desirable land parcels; conventional sewers have been installed at tremendous cost to the homeowners serviced; and ST-SAS's have been constructed that cannot function properly, therefore contaminating the very environment that made the site so attractive originally. The problem has become so acute that the 92nd Congress specifically directed the Environmental Protection Agency (EPA) in Section 104(q)(1) of Public Law 92-500 to conduct a comprehensive program of research and investigation...eliminating pollution from sewage in rural and other areas where collection of sewage in conventional, community-wide sewage collection systems is impractical, uneconomical or otherwise infeasible, or where soil conditions or other factors preclude the use of septic tank and drainage field systems.

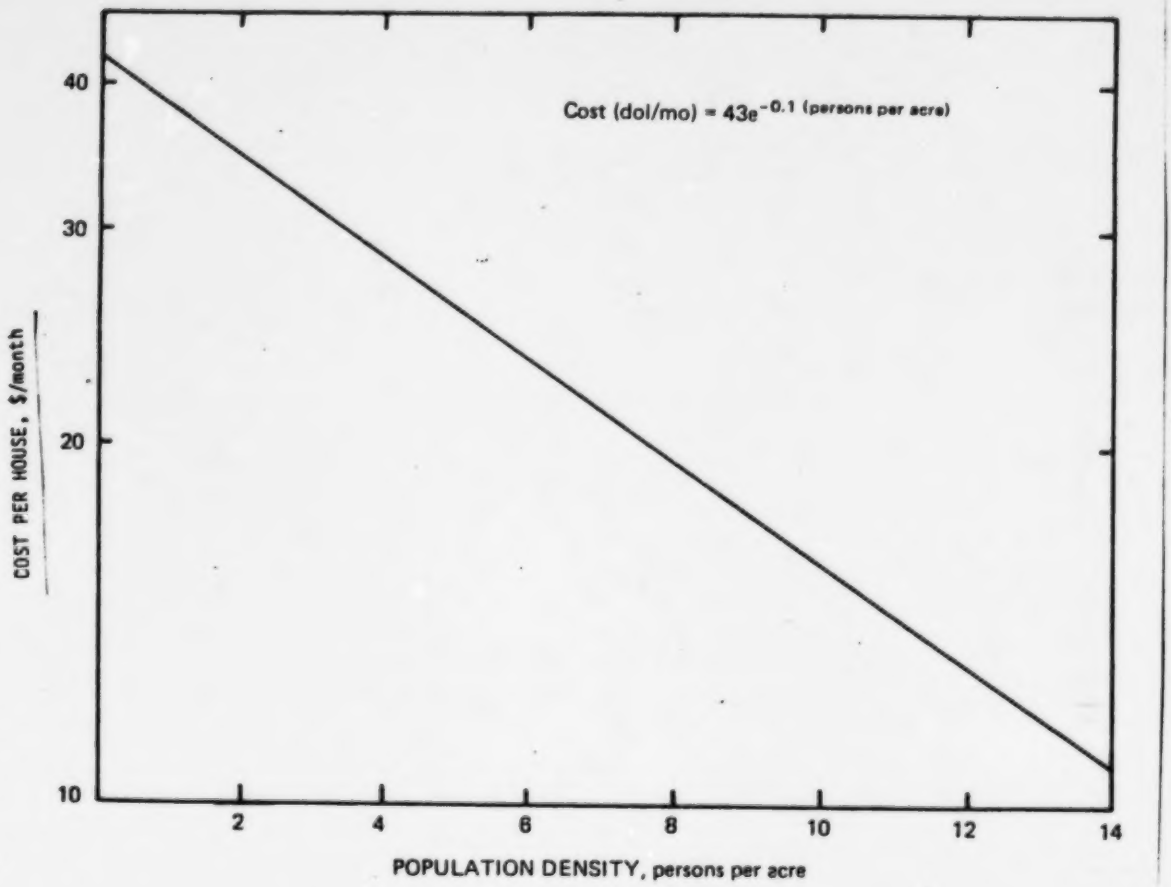

Figure 1. Monthly cost of gravity sewers (Kreissl, 1977)

Given any dilemma of this type mankind has always responded with technological alternatives to relieve such problems. The technological alternatives developed over the past two decades vary from near-elimination of water-carriage for human wastes to alternative onsite and collection technologies which overcome site constraints and/or significantly reduce the cost of environmental sanitation.

2 ALTERNATIVE SEWER TECHNOLOGIES

The three basic types of alternative collection systems discussed herein are pressure, vacuum and small-diameter gravity (SDG) sewers. Their descriptions and histories of use are provided below. All three have been designated as "Alternative Technologies" under the provisions of the Clean Water Act of 1977, thereby being eligible for 85% rather than 75% Federal funding. After 1 October 1984, conventional

technology funding will be reduced from 75% to 55%, and innovative and alternative technology funding will drop from 85% to 75%, thus increasing the incentive funding increment from 10% to 20%.

2.1 PRESSURE SEWERS

Although sewage pumping has been practiced for many years in municipal systems in the form of lift stations and force mains to avoid excessive depths of cut, and in many individual homes in the form of ejector of sump pumps, the wholesale use of small-diameter pressure collection systems did not emerge until the latter part of the 1960's. The chief impetus at that time was provided by the late Gordon Maskew Fair who proposed that small-diameter pressurized sewers be placed inside larger combined sewers to carry sanitary sewage. Although the "sewer-within-a-sewer" concept was not found to be entirely feasible in a resulting study (ASCE, 1964), the use of pressurized sewers carrying ground sewage was feasible. This study was performed by the American Society of Civil Engineers (ASCE) for the Federal Water Pollution Control Administration and included numerous research studies on such topics as household wastewater generation patterns, critical velocities of flow, alternative system layouts, and prototype grinder pump (GP) performance.

The advantages of pressure sewers are primarily related to installation costs and inherent system characteristics. Because these systems all use small-diameter plastic pipes buried just below the frost penetration depth, their installation costs can be quite low compared to conventional gravity systems in low-density areas. Other site conditions that enhance this cost differential include hilly terrain, poor load-bearing soils, rock outcropping, and high water tables. Because pressure sewers are sealed conduits, there should be no opportunity for infiltration, and treatment plants can be designed to handle only the domestic sewage generated in the homes serviced, excluding the infiltration that occurs in most gravity systems.

As with any technology, certain disadvantages also exist. The disadvantages of pressure sewers include lesser-known and potentially higher operation and maintenance costs related to the use of mechanical equipment at each point of entry to the system. Also, the characteristics of the wastewater may pose special design problems for the engineer which differ from conventional treatment plant design practice.

The two major types of pressure sewer systems are the GP system and the septic tank effluent pump (STEP) system. These are depicted in Figures 2 and 3. From these figures it is obvious that the major differences between the alternative pressure

systems are in the onsite equipment and layout. Some subtle differences also exist in the pressure main design methods and in the treatment systems required to reduce the pollutants in the collected wastewater to an environmentally acceptable level. Neither pressure sewer system alternative requires any modification of household plumbing, although neither precludes it if such modifications are deemed desirable.

As noted above, the isolated pumping of sewage and septic tank effluent has been practiced for many years. The first apparent attempt to use a modern pressure sewer system was reported in 1968 (Clift, 1968), but the system described did not employ the techniques and materials that are now considered standard design practice. To serve 42 customers with conventional gravity sewers in low-lying areas of Radcliff, KY., it would have been necessary to finance $3,170 per connection, while the prototype pressure sewer system cost only $1,346 per connection. This prototype design used pneumatic ejector units at each connection, which discharged into a 3-inch (97.6 cm) cast iron lateral and a 4-inch (10.2 cm) cast iron main that emptied into a gravity sewer. Even though mechanical and electrical problems were encountered that eventually caused abandonment of the system, Clift reported that during the first 3 years of operation, no odors or blockage of pressure lines occurred. Severe corrosion was encountered, however, and found to be the primary cause of the electrical and mechanical component shortcomings.

Since the above initiatives and subsequent demonstration projects sponsored by the U.S. Environmental Protection Agency (EPA), Farmers Home Administration (FmHA), and private investments, the pressure sewer concept has rapidly advanced. In 1977 it was determined that nearly 80 pressure sewer systems were either in operation or design/construction in the U.S. Of the 59 operating systems identified at that time 83 percent were GP systems and 17 percent were STEP systems (Rezek, 1983). The preponderance of GP systems was likely related to the early Federal demonstration projects which were all based on the GP concept. STEP systems were initially funded by private entities and the Farmers Home Administration of the Department of Agriculture, but were later included in the EPA demonstration program.

Both variations in pressure sewer technology were first summarized in a useful format in 1977 (Kreissl, 1977). Review

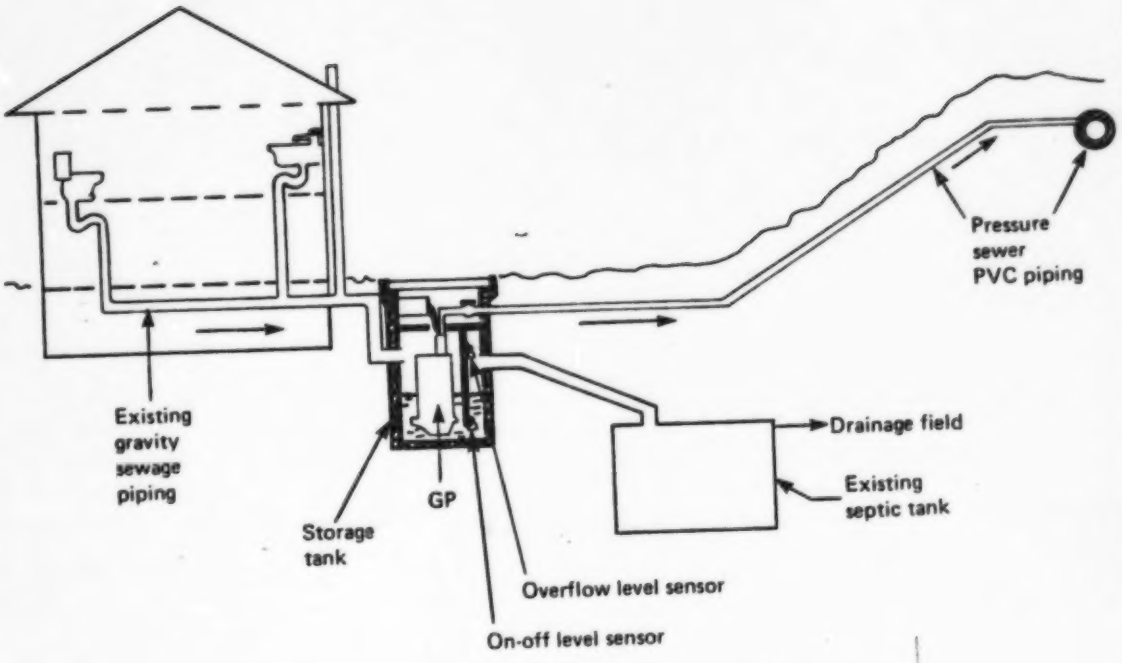

Figure 2. Typical grinder pump installations (Kreissl, 1977)

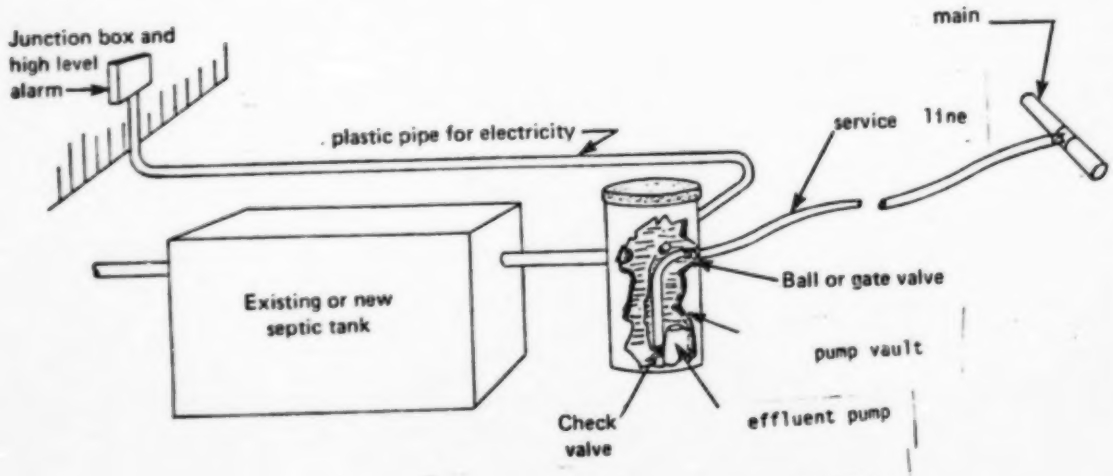

Figure 3. Typical STEP system (Kreissl, 1977)

of recent EPA Construction Grant projects involving Innovative/Alternative (I/A) Technologies reveals that about 2/3 of the 146 small community wastewater collection systems funded under this program are pressure sewers. The remaining one-third are nearly all small-diameter gravity systems. Seven of the 146 systems are vacuum sewers.

2.2 SMALL-DIAMETER GRAVITY SEWERS

Small-diameter gravity (SDG) sewers have also been called "Australian" sewers owing to the country of their first extensive use (since 1961). The cause for this development and use in both Australia and the U.S. was the prohibitive cost of conventional sewers for rural community wastewater conveyance. A schematic diagram of an SDG sewer is presented in Figure 4.

In essence, there are two types of SDG sewers, those with relatively constant grade and those with variable grade. Both types utilize small-diameter plastic pipes and carry septic tank effluent. The septic tanks are required to remove grease, grit and other heavy solids to minimize the need for maintaining scouring velocities in the sewer.

The advantages of SDG sewers over conventional gravity sewers include lower capital cost due to reduced pipe and installation costs, cleanouts in place of manholes, reduced lift station

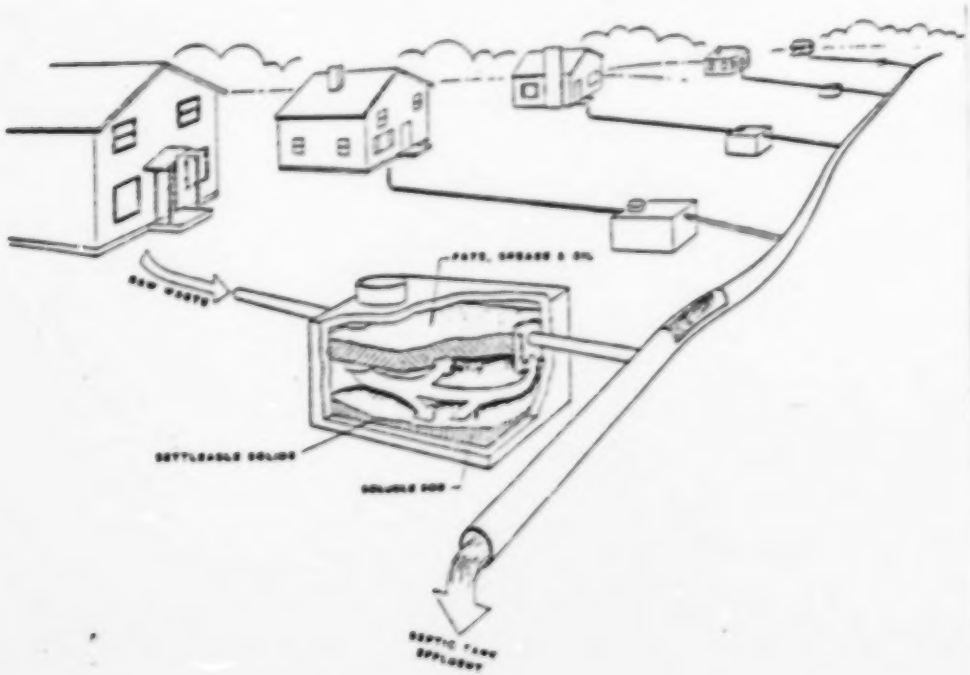

Figure 4. Schematic of Small Diameter Gravity System (Otis, 1981)

sizes due to flow peak attenuation by septic tanks, reduced infiltration and inflow (I/I), and potential reduction in treatment costs due to septic tank pretreatment. Disadvantages include the continued need to maintain and pump septic tanks and the special design problems relative to odor and corrosion inherent with septic tank effluent.

The first major SDG sewer in the U.S. was constructed in 1977 in Westboro, Wisconsin. This system has had an excellent record of operation, only requiring pumping of septic tanks every three years. This system has over 85 connections, serving about 200 people. The system was designed in accordance with the guidelines of the South Australia Department of Public Health, with certain modifications required by the Wisconsin Department of Natural Resources. These modifications required manholes at the upstream end of each line, at all junctions, and at intervals of not more than 600 ft (180 m).

A smaller (10-connection) system in Mt. Andrew, Alabama, was constructed in 1975 with a variable grade approach and no manholes or cleanouts. It has provided several years of maintenance-free performance, with the exception of septic tank pumping. The USDA Farmers Home Administration staff employed their own set of design criteria. These criteria are based on the use of a special two-compartment septic or interceptor tank which further minimizes surge conditions at peak flows by a restricted orifice outlet from the second compartment. In this manner, the system pipe size was minimized.

Experience with these systems had indicated that manholes should be avoided as they represent a source of additional water, grit and other debris. Non-corrosive materials must be incorporated in the design. Based on both of these systems, Otis (1978) has proposed revised design criteria, shown in Table 1.

After the two initial U.S. installations and the heightening of USEPA, FmHA and state interest in the need to provide low-cost sanitation in small communities in the late 1970's, the SDG concept has rapidly developed as an effective pollution abatement concept. As of August, 1982, approximately 25 percent of the small community alternative sewer projects funded under the I/A setaside of the EPA Construction Grnts Program have utilized SDG systems. Also, in non-EPA projects the SDG sewer has found numerous applications due to its low capital cost and non-mechanical nature, which makes it attractive for small communities which must provide the necessary operation and maintenance (O/M) without assistance.

TABLE 1

RECOMMENDED DESIGN CRITERIA FOR SMALL DIAMETER GRAVITY SEWERS DEVELOPED FROM THE WESTBORO SYSTEM EVALUATION (Otis, 1981)

PARAMETER	RECOMMENDED VALUE	COMMENTS
Design Flow	1.0 - 1.1 gpm/conn	Measured peak flow from septic tanks (Baumann, et al, 1978; University of Wisconsin, 1978).
Design Depth of Flow	Sewers may be depressed below hydraulic grade line (MGL)	Continuous fall of hydraulic grade line with maximum elevation limited by inlet elevations.
Minimum Pipe Diameter	4-on (10-cm)	Most house laterals 3 to 4-in and cleaning equipment readily available.
Minimum Velocity	None	Grit, grease and large solids are removed in septic tanks.
Minimum Slope	Inflective	
Pipe Materials	Plastic	
Pipe Roughness Coefficient	Manning's n = 0.013	
Alignment	Curvilinear	Horizontal and vertical planes
Manholes/Cleanouts	Manholes at major junctions only, cleanouts at upstream ends and at regular intervals.	Locate cleanouts at high points in lines to serve as gas vents.
Septic Tanks	Minimum detention time = 1 to 2 days with baffled outlet no larger than sewer diameter	Small outlet prevents large solids from entering system.

2.3 VACUUM SEWERS

The vacuum sewer concept was first patented in the U.S. in 1888 by Adrian Le Marquand. A generalized modern vacuum sewer is depicted schematically in Figure 5. Vacuum systems depend on a central vacuum source constantly maintaining 15 to 25 inches of mercury on small-diameter collection mains. A gravity vacuum interface valve separates atmospheric pressure from the vacuum in the mains. The valve can be either in the home sanitary sewer service line or in a vacuum toilet. When the interface valve opens, a volume of sewage enters the main, followed by a volume of atmospheric air. After a preset interval, the valve closes. The packet of liquid, called a slug, is propelled into the main at a high velocity by the differential pressure of vacuum in the main and the higher atmospheric pressure air behind the slug. After a short distance, the slug is transformed into foam and the momentum is imparted from the air to the sewage through shear forces. Eventually friction slows the sewage velocity, and it then flows to the lowest local elevation by gravity. When the next upstream interface valve operates, identical actions occur, with that slug breaking down and air rushing across the second slug. That air then impacts downstream liquid, lifts it and forces it further down the system. After a number of operations, the first slug arrives at the central vacuum source. When sufficient liquid volume accumulates in the collection tank at the central vacuum source, a transfer device, such as a sewage pump, delivers the accumulated sewage to a treatment plant.

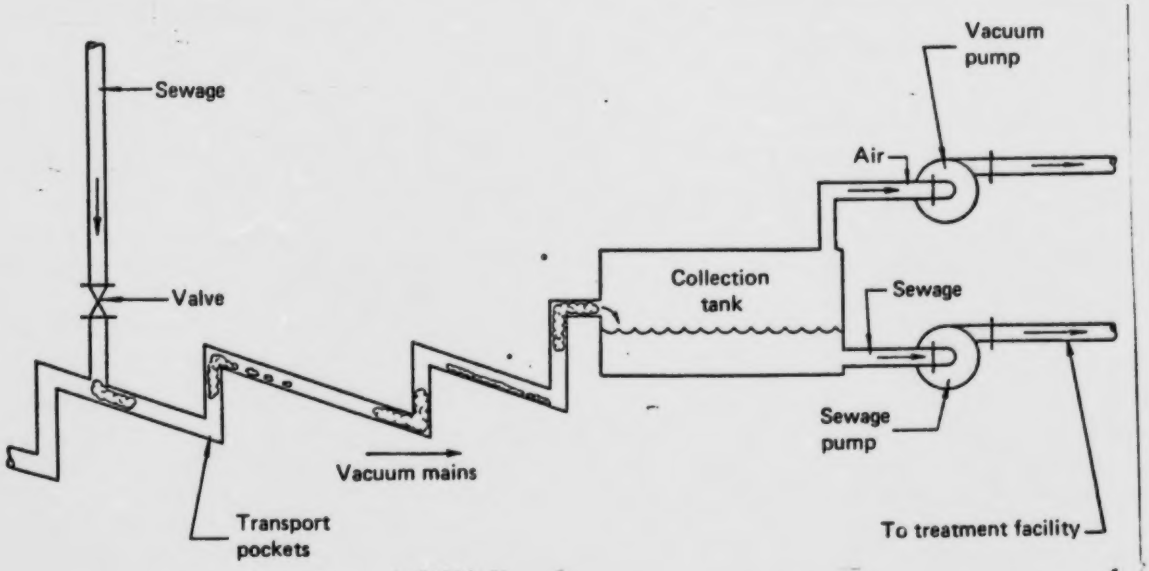

Figure 5. Elements of a vacuum sewage system

Although several types of vacuum equipment and designs are available, they all operate on the general principles described above. The first commercial application of vacuum sewers was in Sweden in 1960 (Nilsson, 1979). These systems employed vacuum toilets, but subsequent developments have tended to utilize normal or gravity-based flow reduction household plumbing fixtures with subsequent transfer of the combined wastewater to the vacuum sewer main through a single interface valve. This form of vacuum sewerage offers reduced power consumption, since the vacuum required to operate vacuum toilets is significant. By 1977 there were seven U.S. vacuum systems in operation. A review of I/A small community projects in late 1982 revealed that 7 of 146 were vacuum systems. At least 4 more were under design and/or construction according to one vacuum equipment supplier (EPA, 1982).

The advantages of vacuum sewers over conventional sewers are similar to those previously stated for pressure and SDG sewers, reduced capital costs due to small plastic pipe use and reduced depth of installation, especially where gravity systems require multiple lift stations. The unique advantages of vacuum systems are the substantial dissolved oxygen content of the wastewater, the centralized power utilization at the vacuum station, and the reduced concern for exfiltration from the system. Disadvantages compared to other alternatives include a higher energy requirement per unit volume of wastewater transported, greater potential for infiltration, PVC pipe need for exact grade alignment during installation, and a limitation on allowable system lift due to the vacuum limit.

Design parameters include a total headloss of 13 feet (4m); pipe sizes of 3, 4 or 6 inches (1.2, 1.6 or 2.4 cm); slope of 0.2 percent in the direction of flow (except when ground slope exceeds this value, ground slope is used); 45 degree lift angles; distance between lifts not less than 10 ft (3.0m); lifts < 5 ft (1.5m) high; minimum vacuum at collection station of 18 ft (5.5m) of water; minimum vacuum at farthest interface valve of 5 to 11.33 ft (1.5 to 3.5 m) of water; peak flow design (3.5 X average flow); and a Hazen-Williams C=150 for PVC pipe. Generally, the maximum length of a 3inch (1.2 cm) line is limited to 800 ft (244m), and for 4 in. (1.6 cm) line the maximum is 2,000 ft (610m) (Pacheco, 1982).

3 PRACTICAL APPLICATIONS

All of the alternative systems can be advantageously utilized in certain rural community applications. Each has certain unique characteristics which may dictate its use under a

certain set of circumstances, which requires that each potential application be analyzed for the most cost-effective system in that specific set of local conditions. The following discussion attempts to generalize the relative merits of each collection alternative with regard to certain physical, administrative and technological constraints which may exist at a given site. Because of the general nature of such an analysis and the probability of contradictory constraints at real project sites, these generalized statements should be regarded only as assistance to the engineer in preliminary assessment of potential collection system choices.

3.1 TOPOGRAPHY

In rural areas with hilly terrain, the already high cost of conventional sewers are made even more acute by multiple lift stations. Although less expensive, the cost of SDG systems can be greatly increased by this same need. If the required lifts are relatively small, vacuum sewers may be feasible, but not for major lifts. Both types of pressure sewers are quite amenable to uphill runs, but incur cost increases in certain undulating terrains. Probably the best cost-effective solution would be a mixed one employing two compatible types of collection, e.g., SDG and STEP.

3.2 GEOLOGY/HYDROLOGY

Conventional sewers incur severe increases in costs where rocky or high groundwater conditions are encountered. Due to their reduced depth requirements, pressure and vacuum sewers become even more cost-effective under these conditions. SDG sewers may fortuitously have similar advantages, depending on their design, but they generally would not completely avoid some of these conventional sewer construction problems.

3.3 CLIMATE

In warmer climates conventional sewers have developed sulfide problems. Because of their inherent use of septic tanks STEP and SDG systems already have a significant sulfide problem. Larger GP systems have demonstrated similar problems, especially during warm periods. Vacuum sewers alone would appear to be best suited for preventing sulfide problems due to the inherent turbulence of the flow and associated opportunities for dissolution of oxygen into the wastewater. In cold climates, insulated plastic pipe has been demonstrated to overcome the

need for greater pipe depth due to increase frost penetration for pressure sewers. This technique might be equally effective for vacuum sewers, but it has not yet been demonstrated. SDG systems would be less likely to freeze than conventional gravity systems due to the elimination of manholes.

3.4 POPULATION DENSITY AND GROWTH

Conventional sewers are advantageous in urban areas with greater population densities. Due to their high cost per unit length and the greater length required per connection in rural areas, they are generally not cost-effective. Vacuum sewers are also sensitive to population density due to limiting line lengths, and have an optimum cost-effectiveness when design populations match available vacuum station sizes. SDG systems, due to their reduced minimum velocity requirements, can handle a wide divergence between initial and ultimate design populations. Pressure sewers depend on the type of design chosen. GP systems require minimum scouring velocities to be reached daily. Therefore, a low ratio of initial to final design population will likely require periodic flushing of the main. STEP systems, like SDG sewers, carry septic tank effluent and are not constrained by lower initial flows. Flows in excess of STEP system design capacity can be accommodated by use of timing controls which provide pumping of wastewater during otherwise low-flow periods of the diurnal cycle. Also, some SDG sewers are designed for half-full flow, which permits a significant increase in available capacity.

3.5 AVAILABLE MANAGEMENT

The management needs for conventional sewers are well documented. Given the simple nature of SDG systems, the management needs are negligible. Pressure and vacuum sewers are mechanical in nature and have a requirement for reasonably skilled O/M staffs. Although their mainline requirements may be equal to or less than conventional sewers, their on-lot facilities and, in the case of vacuum, central station facilities require trained O/M personnel with appropriate support equipment and ancillary facilities. SDG and STEP systems do require regular pumping of pretreatment tanks, as with onsite systems.

3.6 POWER

Conventional gravity and SDG systems may not require any pwoer for operation if appropriate topography exists. The central vacuum stations of a vacuum sewer are generally supplied with

emergency power sources. Pressure sewers, however, are subject to the reliability of power supples and must be designed in accordance with power outage records for the service area. STEP systems generally accommodate lengthy outages due to inherent excess capacity, in the septic tanks. GP systems may require some form of emergency overflow in areas where outages exceed their limited capacity for storage. Power requirements for the three mechanical systems are lowest for STEP intermediate for GP, and highest for vacuum.

3.7 HABITATION

Most comparisons of systems are based on full-time habitation. It is rare that an entire community is seasonal. More typically, the majority of dwellings may be seasonal, with a small nucleus of full-time residences. Most SDG systems would be relatively unaffected by such conditions, as no minimum velocity is required. Conventional and GP systems, owing to their requirement for minimum velocities, could be significantly affected and require some form of flushing during the off-season. STEP, GP and vacuum systems could be severely limited by long periods of disuse of on-lot facilities if the climate is very cold, unless proper insulation or other design and O/M procedures are employed to counteract the problem.

3.8 TERMINATION FACILITIES

Discharge of the alternative sewer at treatment facilities is discussed in the next paragraph. Discharge into an existing conventional sewer can present several problems for all but vacuum sewers. Another exception might be a relatively small GP system where sulfide generation potential is low. However, when large GP systems and STEP and SDG sewers terminate into an existing sewer, two potential problems exist. First, is the problem of odors, which can be effectively controlled through smooth transition hydraulics, such as drop manholes or tangential discharge below the liquid level in the manhole. The second far more serious problem is corrosion. If the receiving manhole and sewer are constructed of concrete destructive corrosion problems can result if the sulfide-laden sewage constitutes a significant portion of the total sewage flow. Although exact criteria for the threshold flow ratio and the downstream reach of this corrosion is not yet available, there appears to be a need to evaluate the cost trade-offs between a transition (sulfide oxidation) facility and a corrosion resistant modification to the existing sewer and manholes.

3.9 TREATABILITY

Septic tank effluent which is transported by SDG and STEP systems is quite amenable to aerobic biological treatment. In fact, due to the reduced I/I of both systems and the minimal concentration of grease, grit and settleable solids in this wastewater, reduced hydraulic capacity of the treatment facility is feasible, along with elimination of preliminary and primary treatment systems. Special materials of construction and immediate oxygen demand requirements must be considered during the design of treatment facilities for these wastewaters. GP wastewater is stronger than normal wastewater, owing to the elimination of I/I. Although it is amenable to normal secondary treatment systems, the total volume of sludge generated should be similar to the conventional cases which may limit potential savings in reduced hydraulic loading. Vacuum sewers produce a wastewater whose strength lies somewhere between normal and GP wastewater, with a generally high dissolved oxygen due to turbulence inherent in the collection system. This wastewater should be quite similar to normal wastewater with regard to treatment. The effects of this wastewater on primary treatment efficiency are not well-documented.

3.10 PERSPECTIVE

In rural areas conventional gravity sewers are rarely cost-effective. Each of the alternative sewer systems described herein have characteristics which might make them singly or in combination the most cost-effective solution in a given set of circumstances. For example, in very small existing communities with gentle downhill slopes and minimal O/M capability, an SDG system should be strongly considered. Similarly, in small existing communities where the optimum location of treatment and disposal facilities is at a higher elevation than the community, a STEP system must be seriously evaluated. Also, in small fringe areas which are at low elevation in relation to a larger conventional sewer, a GP system could possibly be the optimum choice. In relatively flat areas with reasonably dense suburban development with access to a large existing collection sewer, vacuum sewers should be evaluated as a potential optimum solution.

Combinations of alternative sewers are also feasible as the most cost-effective solution. SDG and STEP systems have been combined with excellent results. Combinations of GP and conventional gravity and of vacuum and conventional systems are also common. The engineer must consider not only each alternative sewer, but combinations which utilize the inherent advantages of compatable systems.

4 PERFORMANCE, OPERATION AND MAINTENANCE

Most engineers have accepted the capital cost advantages of alternative sewers in smaller communities, but many continue to doubt their performance reliability and believe their operation and maintenance (O/M) requirements are high. Recently data on both these factors have shed some additional light on these factors.

One method of measuring reliability is to measure the mean time between service calls (MTBSC) for various components of a system. This parameter, expressed in units of time (usually years), provides a measure of average service life of the designated component before the management authority must provide repair service. For example, if there were 400 pumps in a pressure sewer system and each year 100 pumps required service, the MTBSC of the pumps would be 4 years.
The routine O/M designed to increase MTBSC for any system is commonly referred to as preventive maintenance (PM). Preventive maintenance consists of regularly scheduled inspection and maintenance tasks which prevent or forestall unnecessary emergency repair requirements. The fact that some smaller alternative sewer systems do not incorporate a PM program is due in part to the fact that the tradeoff between MTBSC times and PM programs have not been well-quantified for those systems.

4.1 PRESSURE SEWERS

There are a number of factors involved in an appropriate preventive maintenance program. Among these are supervision and inspection of onsite installations, periodic inspection of mainline and onsite facilities, assistance to excavators on line locations, flushing of mains, exercising valves, cleaning pressurization sumps and other tasks specific to the equipment installed. Administrative tasks including payroll, clerical, budget and billing services are part of the overall management function, but are excluded from the preventive maintenance program as defined here.

An additional factor which must be included in any analysis of O/M is that the first year of operation reflects a greater need for service calls than subsequent years due to unforeseen design and construction problems. Therefore, MTBSC analyses may reflect this phenomenon. Also, most manufacturers provide a one-year warranty on their equipment. Also, many of the data related herein are from early installations which repre-

sented pioneering designs of equipment and systems. Subsequent technology advancement will usually improve the reliability data for any of the technologies discussed.

There are two categories of grinder-pumps (GP's) semi-positive displacement (progressing cavity) and centrifugal. Both utilize cutters prior to the pumping step. The major mode of failure with the former is failure of the flexible boot (stator) which surrounds the rotor. With the latter type most problems have been traced to air binding and locking. STEP systems almost exclusively employ centrifugal pumps which are capable of passing 0.5 to 1.0-in. (1.3 to 2.5-cm) solids.

The O/M information presented herein will deal with onsite and mainline information separately, since the former represents the greatest demand on operating and maintenance personnel.

4.11 Grinder pumps

Even though boot failure is the most common type of semi-positive GP failure, the major causes of these failures have been demonstrated to be faulty pressure switches which cause the unit to run when dry, abrasive materials such as sand, plaster and eggshells in the wastewater, and frequent system pressures of greater than 100 psi (700 k Pa) for long periods. MTBSC data for these GP units have been found to vary between 2 an 5 years (Rezek, 1983).

There are few data on MTBSC for centrifugal GP units. However, available information cites the main causes of failure to be caused by air buildup in discharge lines, grease buildup on level controls, and excessive solids in wastewater which wear cutter bars (grinder) and plug the pump.

The most complete O/M data on centrifugal GP units is from the Apple Valley, Ohio system. At the end of the first two years of operation 43 homes were serviced by the system. Eighty percent of the 23 service calls were due to a faulty level switch design (since abandoned by the manufacturer). During the following 20 months the number of GP's rose to 59, and service calls numbered 48. Of those 48, 26 were related to a severe winter storm. Again, nearly 80 percent of the 22 other calls were related to the outmoded switch being fouled by grease buildup. Over the next 10-month period four more units were added to the system, and eleven more service calls occurred, most frequently for the old switch/grease problem (Rezek, 1983).

Although little independent comparative information is available for GP units, a 1981 questionnaire submitted to four manufacturers revealed the following information (Metropolitan Eng., 1981):

1. Warranty - One-year warranties covering parts and labor for the entire GP unit are standard. Potential for extended warranty varies.

2. Normal useful life of GP - Manufacturers claims vary from 10 to 20 years with proper O/M.

3. Most likely failure components - Manufacturers cite seals, electrical controls and cutters as the likely O/M-intensive components, with some additional concern for float switches and bearings.

4. Most likely cause of malfunction - Grease and grit are both cited by the respondees.

5. Recommended number of spare GP units - Manufacturers recommend 5% of the total number of units installed, with a potentially higher number for very small systems.

6. Estimated MTBSC for GP unit - Respondees (2 of 4) estimated MTBSC to be from 1 to 5 years.

7. Operator training offered - All manufacturers offer operator training for field and shop O/M services.

This study also included a test of all four GP units' ability to grind and pass a variety of plastic, paper and fabrics which have been known to be discharged from households. All four units handled these materials without any apparent difficulty.

Finally, the quantitative value of preventive maintenance for GP onsite units is not fully defined. At Apple Valley a quarterly inspection of all units is performed. Conversely, the small system at Cuyler, New York incorporates no preventive maintenance programs. However, the value of annual inspections and cleaning of GP vaults should be similar to that usually recommended for STEP units. Although some GP installations do include such inspections/cleaning, they are not specifically recommended by the manufacturers.

4.12 Effluent pumps

STEP system onsite installations may vary more than their GP counterparts due to the fact that the latter are generally sold as a complete package, while the former may sometimes be "engineered" from several vendor sources. In some cases this engineered approach has resulted in increased maintenance requirements do to design oversights or errors or improper construction practices.

As with GP systems, in expanding service areas one of the major demands on the O/M staff is likely to be supervision and coordination of onsite facility installations. In stable population locations this activity is minimized. Although not specifically included in the O/M requirements as described in this chapter, comments are often noted in the literature to the effect that the total O/M required a specific number of manhours associated with this growth factor. Studies of several GP and STEP systems in expanding areas have shown that from 10 to 33 percent of the management staff time was required for this function.

STEP systems at Port Charlotte and Port St. Lucie, FL, and at Coolin and Kalispell, ID, include over 841 pump installations. The Florida locations are important because of the duration of operation; one area has been in operation since 1970. In Idaho, the more than 588 pumps represent a sizable system. Experience at these locations has been positive and is expected to improve because many early problems have been identified and corrected.

Installation problems can account for a significant percentage of system falures. Twenty percent of the service calls for pumps are ascribed to faulty installation at Port St. Lucie. Likewise, in Idaho, electrical problems discovered at installation or shortly thereafter were significant. As effluent pump installations become more numerous, it is reasonable to expect that installation quality will improve (Rezek, 1983).

The Florida systems originally used pressure switches for level controls. Nearly 20% of service calls at Port St. Lucie were related to pressure switch failures. Even though these switches have an average life of 4 years and cost approximately $15,000 to replace, some have been replaced by the more reliable mercury float level switches. A similar problem occurred at Manila, CA, where level control maintenance represented about one-half of all service call time requirements in the first 18

months of operation (Winzler and Kelly, 1982). The sonic level controllers were primarily responsible, and replacement with float controls has since occurred.

A difficulty encountered in assessing STEP system reliability is inherent in the manner in which service records are kept. Problems with pumps are not necessarily reflective of the total scope of system problems. For example, of the 191 units installed at Port St. Lucie, maintenance records are fully available for only 87. These records indicated 58 service calls during a five year period; however, maintenance personnel report about 5 to 8 service calls per month. Hence, assuming an average of 6 service call per month for the 5 year period (360 calls), roughly 16% were judged to be pump related. This figure compares well with data from the Idaho systems where 12% (30 out of 250 service calls in a 2 year period) of calls were due to pumps. Table 2 illustrates the distribution of 1979 service calls for the Glide, Oregon system which consisted of 328 installations at that time (Bowne, 1981).

TABLE 2. DISTRIBUTION OF SERVICE CALLS-GLIDE, OREGON

Description	Number of Calls	
Electrically Related:	22	
Breaker thron		6
Loose level control connection		5
Power turned off by homeowner		3
Incorrect level control adjustment		3
Level control caught on pump cord		2
Short in panel		1
Burned out relay in panel		1
Water entered panel		1
Pump Related:	10	
Clogging		5
Impeller bound by iron sulfide		4
Capactor		1
Burned out motor, seal or bearing		0
Tank Related:	6	
Settlement		5
Leakage		1
Miscellaneous:	15	
Nothing wrong		7
Clogged building sewer		4
Vandalism		2
Homeowner drunk or senile		2
Check valve		0
Total	53	

MTBSC information for several STEP installations is shown in Table 3.

TABLE 3. MTBSC DATA FOR STEP ONSITE SYSTEMS

Location	Base No. of Installations	Period[1] (yr)	MTBSC[2] (yr)
Port St. Lucie, FL	87	5	3.6
Port Charlotte, FL			
Sec. 18	29	8	6.3
Sec. 54	33	6	7.7
Manila, CA	254	2	3.5
Glide, OR	328	1	6.2

1. Period of time over which analysis made

2. Does not include preventive maintenance or septic tank inspection and/or pumping

Preventive maintenance plays a major role in reducing system difficulties. Originally, the Florida systems scheduled preventive maintenance calls every three years. These are now performed annually. Reduced service calls are attributed, in part, to more frequent preventive maintenance. The Idaho system also schedules one preventive maintenance call per year, at which time the pumps are inspected and chambers are hosed to remove buildup of oils, greases and scale. At Glide the annual inspection involves visual checks, pump vault washdown when required, and septic tank sludge and scum accumulation measurements. At Manila, annual O/M manpower requirements are inordinately high because of the arbitrary requirement for quarterly maintenance. No other system utilizes a preventive maintenance schedule of less than one year.

4.13 Mainline and miscellaneous

Mainline O/M is similar for both GP and STEP systems even though the hydraulic design approach to each is quite different. Neither requires manholes, while both require cleanouts at termination points and at intermediate locations where pipe sizes change or pipe junctions occur. Mainline shutoff valves are suggested at 600 ft. and 1000 ft. intervals for high and low density service populations by Florida Guidelines (Florida, 1981). Air release valves are generally required near high points in the system where the downstream slope exceeds 10% and the length of run is substantial. In some systems where topographic conditions are severe, pressure-sustaining valves have been utilized. All of these valves represent a significant O/M requirement.

Bowne and Ball (1981) indicate that the preventive maintenance (PM) program for Glide includes annual exercising of shutoff valves and periodic (unspecified intervals) inspection of air release valves, with flushing as required. Flushing of mains has not been necessary for any STEP systems and is generally not practiced for GP systems, except in developments where early hydraulic loads are but a fraction of the system design loading. Flushing programs are maintained at the Horseshoe Bay and Point Venture, Texas GP systems. The Apple Valley system PM program incorporates annual exercising of shutoff valves and flow reversal in looped lines. One manufacturer of a GP system has suggested periodic mainline pressure measurement to determine if and when flushing might be necessary.

Actual mainline emergency maintenance has been extremely rare and usually associated with excavation damage to the pipe. Freezing problems resulted in a line break at Weatherby Lake, and 8 instances of frozen mainlines were reported during a nearly 4-year period at Apple Valley. Freezing problems are avoidable with proper design, as systems in northern Canada have operated successfully without these problems. The early Grandview Lake, Indiana system suffered pipeline damage by excavation, earthslides and improper construction.

Other pressure sewer system O/M problems have resulted from odors and corrosion. The latter is considered the biggest problem for system valves. The STEP systems in Florida and a system in Oregon had these problems with brass valves, but have found bronze valves to perform adequately. Other valve O/M problems have included grease plugs in service line check valves, frozen check valves, and leaking check and air release valves. Proper design and choice of construction materials should minimize these O/M problems.

The corrosion problem is most severe in STEP systems due to the sulfide concentration of septic tank effluent. Similar problems can occur in GP systems, particularly larger systems, where the undiluted (due to lack of infiltration) wastewater has a significant detention time. Therefore, all pressure sewer systems require designer attention to materials of construction which are exposed to the wastewater or atmosphere of the pressure sewer system. With such proper design consideration, unnecessary O/M problems can be avoided.

Other problems have been documented at several locations. The most commonly observed location for odor problems is at lift stations. Several novel methods have been used to overcome the odor problems. For example, odors from the lift stations at Kalispell and Glide are vented to drainfields for soil scrubbing. At some smaller systems when odors are found, the remedy involves resetting the level controllers or timers on the pumps for more frequent pumping events. Weatherby Lake adds hydrogen peroxide (0.06 m^3/day (15 gal/day) of 35% hydrogen peroxide) at three lift stations for odor control.

As noted above for corrosion, good design practice can minimize unnecessary O/M problems. Odor abatement systems where unfavorable odors occur can represent an O/M requirement in themselves, depending on the abatement system chosen, and must be included in the overall O/M plan for the system. For example, the soil filter approach may require periodic wetting, while the warm weather peroxide system requires the cost of chemicals and labor to makeup chemicals and maintain the feeding system.

4.2 SMALL-DIAMETER GRAVITY SEWERS

The U.S. experience with small-diameter gravity (SDG) sewers is so limited that O/M data are almost negligible and are from only three sources, i.e., Mt. Andrew, Alabama, Westboro, Wisconsin and Avery and Shoshone County, Idaho. The only O/M problems of significance on the Mt. Andrew and Westboro systems with 8 and 6 years, respectively of operating experience, has been the pumping of septic tanks. At Mt. Andrew some of the small tanks employed required pumping in a little more than one year. However, at Westboro the residential septic tanks are pumped at 3-year intervals, while tanks serving commercial establishments are pumped annually.

After 18 months of operation, the Mt. Andrew system was dug up at several locations to inspect the condition of lines with respect to potential blockages, as the SDG mains had operated without failure and had not been flushed during this period (Simmons, 1982). Sections of pipe at low points in the system (there are 5 inflections between positive and negative gradients) revealed a thin, grayish residue, but no accumulated heavy solids. Similar monitoring of the Westboro system also revealed a thin biofilm after four years of operation with no mainline flushing (Otis, 1981). In this latter system, however, some problems have been caused by the regulatory authority's requirement of manholes in the system. Grit entry through these structures has, fortunately, only accumulated within the manholes themselves.

Some odor problems have been experienced where SDG systems have incorrectly incorporated manholes. The Idaho systems experienced odors from the terminal manholes where SDG effluent entered a large interceptor. This problem was eliminated by proper hydraulic modification to a drop manhole design.

The Australian experience with SDG sewers is quite significant compared with that in the U.S. Since 1960, there have been dozens of SDG systems installed in South Australia serving over 26,000 users with more than 360 miles (580 cm) of SDG mainline. As many as 60 new SDG projects are possible by 1990. Early installations utilized vitrified clay piping which was found to suffer from root penetration and blockage. Since then the use of PVC pipe with solvent-welded joints has eliminated this problem.

In a 1978 study of 7 existing SDG systems in South Australia it was noted that regular main flushing was employed at only 3 locations and those three systems did not experience blockages (Marks, 1978). Annual flushing is recommended by the South Australia Health Commission to prevent the accumulation of gas-producing solids. However, it has been noted that systems that were not flushed did not apparently suffer any major blockage problem (Marks, 1978).

Septic tank pumping has normally been scheduled for every 5 years. Addition of hydrated lime to freshly pumped septic tanks has also been practiced to reduce the occurrence of odors from house vents. It is theorized by the Australians that the formation of a scum layer or crust after about 12 months of operation after pumping eliminated odor problems.

During the interim period odors were usually noted on calm, warm nights from the vents of houses located in high areas and from houses where overuse of bleach and disinfectants had been noted (Marks, 1978).

Contrary to U.S. pressure sewer experience, corrosion of concrete manholes was not found.

In either the variable-grade or constant-grade design approaches, it is generally true that SDG sewer depths will be greater than for pressure or vacuum sewers. This greater depth might suggest lower mainline O/M costs due to reduced danger or damage by excavation. However, the potential need for line flushing must be considered greater than for a STEP or vacuum system until more experience is gained on the actual necessity for this O/M task. Of course, if lift stations are required, the mainline O/M cost will become quite significant.

Septic tank pumping requirements would be identical to those for STEP systems, since the need to avoid solids carryover is identical in each system.

4.3 VACUUM SEWERS

Many of the observations noted under pressure sewers are applicable to vacuum sewers as well. The likelihood of higher maintenance requirements during the startup phase due to foreign materials entering the system during construction and connection phases is to be expected. Mainline repairs would also be similar for vacuum systems since the piping materials and shallow burial depths are basically the same.

There are three primary areas of potential maintenance with a vacuum sewer, i.e., the interfacing valves, the vacuum main and the vacuum station. Historically, the interfacing valves, particularly the controller mechanisms, have been the primary source of O/M service call demand. Manufacturer improvements in the controller have not been fully evaluated from an operational standpoint because of insufficient field data at this time.

In accordance with manufacturers, Eblen and Clark (1978) recommended an annual inspection of valves, valve pits and wastewater sumps (to prevent increased service calls due to grease accumulation) in addition to inspection and cleaning of valve breathers, check valves and solenoids. The time

requirement for this onsite preventive maintenance is regarded as minimal by manufacturers, but was estimated by Eblen and Clark to require 3 man hours per year, including the removal of accumulated grease. Based on minimal additional information, an annual estimate of one man hour per valve should be reasonable.

In the same manner as pressure sewers, vacuum sewer onsite component reliability may be expressed as mean time between service calls (MTBSC). Cooper and Rezek (unpublished) determined MTBSC data on several early systems, as shown in Table 4.

TABLE 4. MEAN TIME BETWEEN SERVICE CALLS FOR ONSITE EQUIPMENT IN VARIOUS SYSTEMS

System Name	MTBSC (years)
Mathews, Virginia	8.33
Plainville, Indiana	3.50
Eastpoint, Florida	3.75
Bend, Oregon	4.00

The early vacuum valve controllers were quite sensitive to moisture, resulting in failures of valve to function, often in the open position which sometimes caused loss of vacuum in the entire system. Continuous cycling of valves often occurred also. New controller designs are purported to eliminate these problems. However, problems such as stuck valves due to grease accumulation or plugged breather tubes are still possible, and therefore, valves will continue to require service calls. Data on systems with the latest valve/controllers are not yet available in sufficient numbers to quantify these improvements.

Emergency maintenance can be initiated by two types of onsite failure modes. A valve stuck in the closed position will eventally result in a sewage backup into the house or nearby surroundings. The homeowner's resulting call to the O/M staff would then initiate the service call. A valve which fails in the open position will cause a loss of vacuum in the system. In most cases this condition activates a low vacuum signal alarm to the utility repair staff. This condition may result in other valves failing to operate and in continuous operation of the vacuum pumps. Therefore, the O/M arrangement must permit rapid response to this alarm.

One additional failure is that of a leak or breakage in the vacuum main. Although underground leaks are less common than breakage due to excavation activity, their occurrence can create a significant problem in detection. Commercial leak detectors are available for these purposes, although vacuum measurements at valves would also be useful.

The predominant U.S. vacuum sewer manufacturer recommends the removal and rebuilding of the valve every five to six years. Clark and Eblen (1978) suggested a major valve repair might be called for every 5 years, requiring five man hours of labor. The present manager of the Country Squire Lakes, Indiana system has routinely been performing this function every four years. Although the manufactuer indicates that this effort involves only about $10 in parts, i.e., new seals, diaphragms, shaft seal and seat, the labor cost or man hours is not specified. It appears reasonable to assume that the travel, removal and shop time required would 5 man hours per repair.

In addition to the interfacing valves, the other major O/M problem relates to the vacuum pump, e.g. oil levels, indicator lights and vacuum chart recorders. Cooper and Rezek (unpublished) also suggest daily tracking of vacuum pump running hours to determine any gradual or sudden increase in the energy required to maintain proper system vacuum. Weekly preventive maintenance and operation includes checking the standby generator fluids and battery, makeup oil for vacuum pumps, and the mechanical seals of the discharge pumps for leakage, as well as cleaning the station and testing the alarm system. Monthly checks of discharge pump couplings and gaskets are also recommended. With liquid-ring vacuum pumps, quarterly checking and tightening of grease cups and glands are recommended. As necessary, 1 to 10 times per year, vacuum pump oil should be changed. This need is determined by the color of the liquid. Annual preventive maintenance includes inspection of discharge and vacuum pump check valves and exhaust lines, oil reservoir, and vacuum pump couplings, as well as lubrication of all motors.

Preventive maintenance (PM) for the vacuum station is estimated by Eblen and Clark (1978) to require 50 man hours per year (twice per week). Few other data sources are specific to vacuum station PM, but Westmoreland, TN has had a malfunctioning alarm system causing the number of daily inspections to increase from one to five. Even at one-half hour per occurrence, a daily inspection should require about 180 man hours annually,

while five would approach 900. Mathews, Virginia was reported to spend between 100 and 200 man hours per year on vacuum station operation/preventive maintenance, while the system at Foxcliff Estates required 120 to 180 annual man hours. Based on the above information it is reasonable to assume that vacuum station operation and preventive maintenance should require approximately 200 man hours per years of O/M staff effort, not including major overhauls of equipment which would probably be performed on a contract basis.

The required frequency of major vacuum station equipment overhauling is difficult to quantify. At Eastpoint, Florida the oil-ring vacuum pumps are to be rebuilt after 6 years of service, along with repairing of standby generators. At Bend, one of the sliding-vane vacuum pumps required major servicing, i.e., new vanes, springs and bearings, after 10-months of operation. An early Bahamian system required vacuum pump overhauls at 6-month intervals due to the effects of highly mineralized tapwater and heavy grease loadings (Cooper and Rezek, unpublished).

Other vacuum station problems which have occurred include solenoid valve failures, sewage discharge through the vacuum pump after sewage pump failure, inadequate sewage pump seals, check valve failures and vacuum pump oil losses and overheating.

Mainline O/M requirements should be quite similar to pressure sewers. Both are usually located just below the frost line, are generally of PVC fabrication, and are equally subject to the damage by excavation. Therefore, in the absence of any mainline O/M information, the O/M requirements for mainlines can be estimated to be about 0.1 man hour per year per user for routine O/M plus a reasonable manpower requirement for each mainline emergency. As with pressure sewers, the number of anticipated incidents of mainline damage will be related to the growth factor of the service area and the capability of the management entity to provide assistance to prospective excavators.

5 COST COMPARISONS

As noted earlier the cost of alternative sewers is extremely site specific. The local conditions will determine the most cost-effective alternative sewer for a given community. In order to accomplish some form of generic comparison Kreissl, et al, (1978) assumed a community size of 500 people (3.5 persons/dwelling) and no topographical or geological constraints

to any of the sewering alternatives. The former assumption allowed the use of empirically developed relationships between population and population density, capital and O/M costs of conventional gravity sewers, and lengths of sewer per dwelling. The latter assumption permited each alternative to be presented at its optimum or lowest cost.

U.S. EPA Construction Grant data on actual costs of conventional gravity sewers for a 5-year period indicated that a conventional sewer would have a capital cost of about $4,900 per dwelling during the first quarter of 1978. The above-noted relationships indicated that the average length of sewer main per dwelling was about 120 ft (37 m). An additional assumption of 100 ft (30 m) of service line for each dwelling was also made, along with determining U.S. average unit costs for system components.

Estimated initial costs for pressure, SDG and vacuum sewers are presented in Table 5. For this exercise it was assumed that a grinder-pump would cost about the same as the cost of replacing the existing septic tank plus the STEP unit, so these alternative designs are presented as a single "pressure sewer" cost.

TABLE 5. INITIAL COSTS OF ALTERNATIVE SEWERS PER DWELLING

Component	Pressure	SDG	Vacuum
Septic tank	$ 400	$ 400	--
Pumping	1,350	--	--
Vacuum-onsite	--	--	$ 900
Service line	300	500	500
Mainline	675	1,700	900
Vacuum station	--	--	525
Construction cost	$2,725	$2,600	$2,825
Capital cost	$3,460	$3,300	$3,580

From Table 5, two conclusions can be drawn. The first is that under unconstrained conditions all three alternative sewers should be considered since their initial costs are quite similar. The second conclusion is that anticipated savings over conventional sewers are almost 30 percent of the capital cost. Actually savings in capital cost have been as high as 90 percent in some instances for pressure sewers because of their ability to serve difficult topographical situations with minimal increase in the unconstrained costs.

Operation and maintenance (O/M) costs are of major concern to the community primarily because they represent a continuing demand over the life of the collection system, and also because they contribute to the present worth of the alternatives in the cost-effective analysis to determine the optimum system.

For reference purpose, Table 6 is a listing of several pressure sewer systems and their reported annual charges for O/M. It is impossible to accurately compare these charges since many

TABLE 6. ANUAL O/M CHARGES FOR PRESSURE SEWERS

Location	Type	Age (year)	Per Household Annual Charge ($/year)
Apple Valley OH	GP	9	62
Golf View Esates, IN	GP	>10	72
Glide, OR	STEP	5	114
Grandview Lake, IN	GP	15	139
Manila, CA	STEP	3	125
Cuyler, NY	GP	5	60
GDU Systems, FL	STEP	13	84 - 100
Quaker Lake, PA	GP	7	145

include treatment and administrative costs (some may even include debt services). The Manila system information is quite complete and represents an extremely conservative approach to STEP sewerage. Of the $125 annual cost $66 was expended on the STEP facilities O/M. Of the $66 nearly $22 was devoted to power and power system operation for the uniquely designed facility, and $32 was for the excessive preventive maintenance program instituted. As with most pressure sewer systems of proper design, the annual cost for mainline maintenance was negligible, i.e., about $2/yr.

In terms of recommended charges for STEP systems and GP systems, it is suggested that annual user charges, excluding debt service and administrative costs, should fall between $50 and $100, unless unusual and site specific circumstances dictate otherwise.

If septic tank pumping is planned at 3-year intervals, for example, and costs $60, the annual cost of this O/M task is $20. If 20% of a 100-home SDG system requires pumping due to eleva-

tion problems, appropriate preventive maintenance, power and apportioned emergency service calls would be basically the same as a STEP system or 1/5 x $50 to $100, or $10 to $20 per user annually. If that same system required a lift station instead of the 20% STEP units, the cost per user could be as high as $50 per year. Mainline preventive maintenance, assuming no flushing, would be less than a STEP system due to greater depth and lower probability of excavation damage. Therefore, one dollar per year per user might be an appropriate estimate of O/M costs.

It is clear from the above discussion, that the O/M cost of a pure SDG sewer is quite low, as little as $20 per year. However, the need for lift stations and other specialized mechanical adjuncts can quickly add significantly to the cost of O/M. The actual O/M cost will be reflective of the local conditions and final systems design.

Total O/M for a vacuum sewer system must include power, preventive and emergency labor requirements, major (contract) repairs, spare parts and supplies. Based on the Bend system study Eblen and Clark (1978) estimated that for a vacuum sewer servicing 50 homes the annual costs would be $40/yr per user for the onsite portion and $44/yr per user for the vacuum station. Cooper and Rezek (unpublished) estimated that preventive maintenance varied from a low of 4 man hours per year per user up to several times that figure. If the above determined preventive maintenance levels of 200 man hours per year per vacuum station and one man hour per year per vacuum valve are assumed along with a reasonable MTBSC for the valves and the vacuum pumping station equipment, the only remaining O/M costs are for power and mainline requirements.

Power demand versus flow was measured at several locations and reported by Cooper and Rezek (unpublished) to vary from 0.04 to 1.6 m^3/kWh. Elben and Clark (1978) measured the total demand at 1.36 kWh/user/day. Data from Westmoreland, Tennessee indicate about 3¢/day/user and from Fairmount, Maryland about 6¢/day/user. Plainville, Indiana power costs indicate that 4¢/day/user is being consumed by the vacuum system. Foxcliff Estates, Indiana costs were found to be between 11 and 12¢/day/user, while Country Squire Lakes, Indiana requires about 3¢/day/user. Based on the above data, power requirements can reasonably be estimated at 1 to 2 kWh per day per user at the local electric rate.

Mainline O/M costs would be similar to pressure and SDG systems, or about two dollars per dwelling served per year.

In summary, although the data are extremely sparse and varied, it would appear reasonable that the above information would permit an engineer to estimate the annual O/M cost of a vacuum sewer system by knowing the number of users, the number of vacuum stations, labor rates, and electric rates for the potential site. For example, a 100-home system on one vacuum station with labor rates of $10 per hour and an electric rate of 5¢/kWh could reasonably be expected to require an annual O/M charge of:

Power	$20.00 - $30.00
Labor:	
onsite	20.00 - 50.00
station	20.00 - 40.00
main	2.00 - 3.00
	$62.00 - $123.00

Comparing alternative sewers to conventional gravity sewers, a study of 132 small conventional sewers indicates that for a conventional sewer servicing a community of 500 with an average of 3.5 persons per home, the annual O/M cost would be $4,800 or about $33.00 per home. This would be slightly in excess of the O/M cost of SDG system, also without lift stations. Thus, on the basis of O/M costs for sewers under ideal topographic conditions, alternative sewers are generally more costly. However, the capital cost of the conventional system would be quite high compared to alternative sewers. Also, since the O/M cost of a conventional sewer is normally quite small compared to amortized initial cost, alternative sewers are clearly more cost-effective in rural areas.

There are several factors which can affect the comparative economics between conventional and alternative sewers and between the different alternative sewers. These factors include proximity of serviced dwellings and new vs old development, in addition to all of the factors cited under Section 3 above.

The proximity of dwellings in the service area will, if they are sufficiently close, allow for combination of onlot facilities. With pressure sewers the use of one pressurization unit for two homes could reduce initial costs by about 1/3, based on the cost estimates presented above. Combinations of three homes on a single unit have been successfully demonstrated (Eblen and Clark, 1978). Similarly with vacuum systems, two

homes serviced by a single interfacing valve would reduce initial costs by about 1/6. Combinations of as many as 8 homes per valve have been successfully demonstrated. In both of the above examples, O/M cost reductions would also be expected, though not in direct proportion to initial costs.

Where existing community wastewater facilities are being modified due to failure of onsite wastewater disposal systems, continued use of existing septic tanks could significantly reduce initial costs of STEP and SDG alternatives. Further reduction could be realized at a terminal treatment facility for both of these alternative sewers by taking advantage of pretreatment by septic tanks and the absence of or reduced infiltration in designing the treatment system. Where the above modifications terminate in an existing conventional sewer, SDG and pressure sewers may require special sulfide oxidation facilities or significant modification to the existing sewer if that sewer and manholes are constructed of concrete.

6 S U M M A R Y

Pressure, vacuum and small-diameter gravity sewers have become a valuable engineering alternative to conventional sewers in the United States over the past fifteen years. Although there remains a need to fully quantify long-term operation, maintenance and performance characteristics, the apparent economic advantages of these systems are sufficient to have caused widespread adoption in rural America.

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